Deformation and Fracture of Nanocrystalline Metals

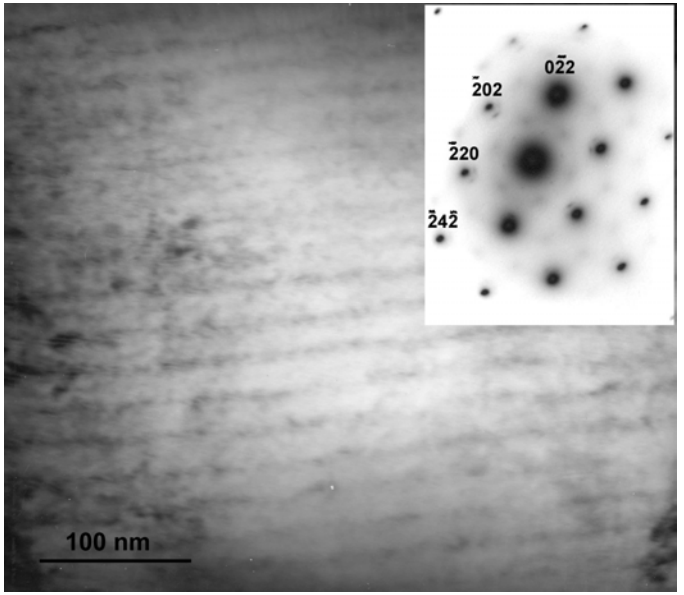
Fereshteh Ebrahimi, University of Florida, DMR Award # 9980213

Nickel/Copper Multilayers

• Nanolayered (5 to 25nm) nickel/copper structures were synthesized via electrodeposition technique.
• Microstructure and the evolution of crystallographic texture were analyzed.
•The deformation and fracture of the multilayers were characterized and correlated with their microstructure.
• The cause of brittleness of these structures were determined and the synthesis conditions for optimum strength and ductility were identified.
• Important technological applications: hard coatings and magnetic devices.

Publications

F. Ebrahimi and J. Liscano, *Materials Science and Engineering* A301 (2001) 23-34.
F. Ebrahimi and A. Liscano, *Materials Transactions, JIM*, 42 (2001) 120-127.
F. Ebrahimi, A. J. Liscano, D. Kong and V. Krishnamoorthy, "Evolution of Texture in Electrodeposited Ni/Cu Layered Nanostructures," submitted to *Philosophical Magazine A*.



Bright field TEM micrograph and the associated diffraction pattern of a deposit with bi-layer thickness of 20nm.

- **Synthesis:** Electrodeposition is an inexpensive and versatile technique for fabricating nanostructures. Methods such as vapor deposition, ion beam sputtering or molecular beam require high vacuum and the deposition rate is very slow. Electrodeposition allows fabricating relatively thick films (30-50 μm), which can be removed from substrates and used for conducting tests such as tensile testing.
- **Mechanical Properties:**Although pure metals such as copper and nickel are very soft, laminated structures made of two or more metals can be very strong and can be used as hard coatings.
- **Magnetic Properties:** Although not an objective of this research, multilayers of a magnetic material such as Ni, Co and Fe and a non-magnetic metal such as copper show GMR (giant magnetoresistance) behavior. This means that their electrical resistance depends strongly on the applied magnetic field. Therefore they can be used in the head of hard drives for computers or as sensors.
- **Why are we doing this project:**
- Multilayers of nickel and copper show very high strengths as measured by hardness, but their tensile strength can be low due to presence of defects. We have determined what makes these materials brittle.
- The strength of multilayers depends strongly on the nature of the interface between the layers, which depends on the coherency of the interface. We have shown that Ni/Cu multilayers with coherent interfaces are quite ductile, however as the layer thickness increases the strength increases but the ductility is reduced significantly. We demonstrated that FCC crystals can cleave in nanostructures.

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Ni-Fe Nanocrystals

• Established the parameters for the synthesis of Ni-Fe alloys via electrodeposition. We were successful in making deposits with grain sizes in the 3nm to 80nm range.

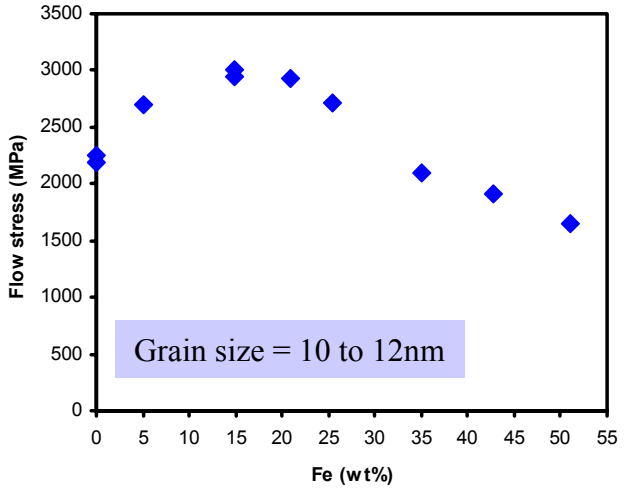
• Characterized the microstructure and strength of the alloys as functions of grain size, iron content and annealing temperature.

• Technological applications include sensors, MEMS, and data storage.

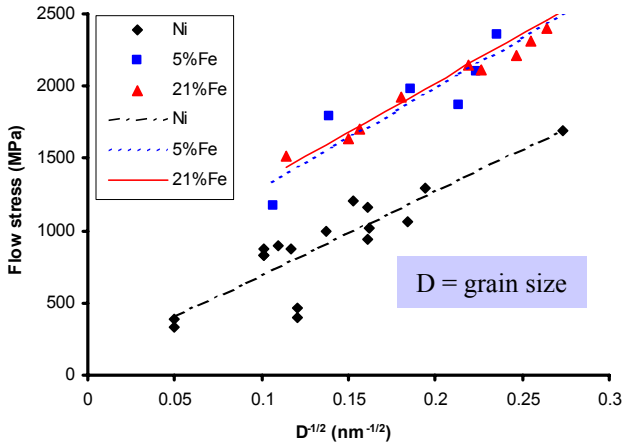
Publications

F. Ebrahimi and Z. Ahmed, " The Effect of Current Density on Properties of Electrodeposited Nanocrystalline Nickel," submitted to *Electrochimica Acta*.

H. Li and F. Ebrahimi, "Synthesis and Characterization of Electrodeposited Nanocrystalline Ni-Fe Alloys", submitted to *Materials Science and Engineering Journal*.



Effect of iron concentration on strength



Effect of grain size on strength

Synthesis: The advantages of electrodeposition are:

Electrodeposition is the most inexpensive method to produce nanocrystalline materials.

The material is almost defect free for example in comparison to gas condensation technique.

Nonequilibrium structures can be easily fabricated; for example, super saturated alloys.

Mechanical Properties: Metallic nanocrystals are very strong. We see strengthening up to approximately 10nm grain size. The problem is that at grain sizes less than approximately 30nm these materials become brittle. We are interested to modify the grain size distribution and composition to obtain the optimum strength/ductility combination.

Applications: Although most of MEMS components are made of silicon, metals can offer better properties such as toughness, electrical conductivity and magnetic properties. Therefore, there is a need to develop small components out of metals that are very strong and/or have special magnetic properties. Electrodeposition is the best technique for filling cavities, therefore, it can be used to fabricate very small components. Metallic nanocrystals can provide very high strengths as well as superior magnetic properties.

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Education/Training/Outreach

• 4 graduate students (Alirio Liscano, Hongi Li, Zunayed Ahmed and Kristin Morgan) participated in research. Kristin Morgan was funded through a fellowship.

• 2 female undergraduate students (Elyssa Cutler and Nichole Whitney) have been trained to electrodeposit, conduct x-ray analysis and perform tensile testing.

• 1 student (Xavier Foltete) from Grenoble National Engineering School in France is performing his training period (3 months) in our laboratory.

• 1 Master and 1 Undergraduate Senior theses were published under this grant during last year.

• Participated (Fereshteh Ebrahimi and graduate student Alirio Liscano) in a workshop for familiarizing the elementary and middle school teachers of the Alachua County with the field of materials science.